A Mixed-Cell Propagation Model for Interference Prediction in a UMTS Network

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Abstract

With the support of mixed cells and hierarchical cell structures in UMTS, propagation information (coverage and interference) between different cell types is required. Here, a mixed-cell propagation model is presented which is suitable for predicting interference in mixed macrocellular and microcellular environments. The main features of the model are described together with examples of interference prediction including C/I and most-likely-server plots. Comparisons between model predictions and measurements for a mixed cell environment are also presented.

1. Introduction

An increasing demand for high bandwidth mobile services has led to the drive for 3G multimedia-capable mobile communications systems. UMTS is a product of this drive, and aims to provide variable-rate data and multimedia services to a variety of geographical environments. It is intended to fully support mixed-cell/hierarchical cell structures with inter-frequency handover, as well as the use of adaptive antenna arrays and asynchronous inter-base station operation [1]. In DS-CDMA, due to its universal one-cell frequency re-use, cell capacity is mainly limited by the interference from other users both within the active cell and from adjacent cells. As such it is vital that the network planner is able to accurately determine this interference so as to maximise the capacity of the network. Interference information is usually obtained from propagation models. Because of the support of mixed cells and hierarchical cell structures, such models need to be able to seamlessly integrate differing propagation characteristics within different cell types. Additionally, the design of adaptive antenna structures relies on the availability of accurate spatial channel information (usually arrival angle information). Time dispersion also has a significant performance effect especially in high-bandwidth digital systems [2], and should therefore be accurately modelled. Thus mixed-cell models must provide wideband information i.e. time, frequency and spatial dispersion information.

An integrated propagation model for mixed macrocellular and microcellular environments is presented in this paper. The main features of the model are described in the proceeding section, together with comparisons between model predictions and measurement data. Results from the model, including C/I, most-likely server, redundancy and outage plots for multiple BSs in mixed environments are presented.

2. Mixed Cell Propagation Model

Macrocells typically cover large (up to 50km by 50km) predominantly low building density suburban and rural areas with irregular terrain, and support low to medium traffic densities. Microcells on the other hand cover smaller (up to 1km by 1km) predominantly urban (high building density) areas, supporting medium to high traffic densities. Additionally, whereas macrocell BSs are usually located above local clutter (e.g. hill tops, high masts), microcell BSs tend to be located below the local clutter, usually on lampposts or building walls. Therefore to predict interference between mixed cells in a UMTS network, models are required that encompass the different propagation characteristics in both cell types: terrain scatter and diffraction, building scatter, roof-top diffraction, and foliage attenuation in macrocells, building reflection/scatter, ground reflection, rooftop and corner diffraction, in microcells.

The model described in this paper considers large areas with irregular terrain but also considers the effects of individual buildings as well as foliage. It is fully polarimetric, and considers foliage attenuation, multiple terrain and building scatter, and combinations of off-axis diffracted and scattered propagation paths. Scattered power is calculated from radar cross-section analysis of terrain pixels and building walls, while the finite conductivity UTD approach is used for estimating diffraction losses. A choice of empirical foliage-loss models is also available to the user.

The model uses a variable resolution DTM to model irregular terrain up to 50km by 50km in size, a 10m resolution raster building database for built-up areas, as well as foliage and ground cover databases in the prediction area. Figure 1 shows a 3D view of a 4km by 4km prediction area used in the model comprising rural hilly terrain overlooking built-up urban areas.

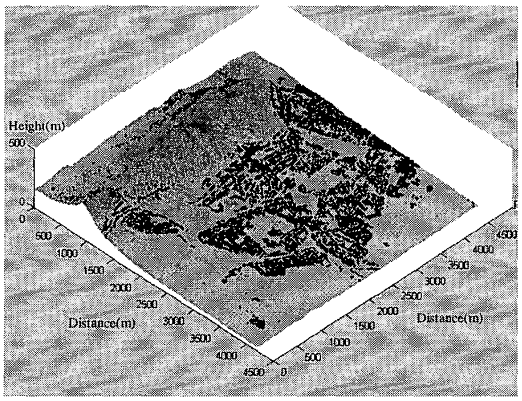

Fig. 1: Mixed macro-micro prediction area

The model is an extension of that described in [3] and [4]. The previous model was optimised for macrocellular environments with high-mounted BS antennas, and also for inter-cellular (both micro and macro) propagation, where rooftop diffraction is the dominant propagation mechanism. As such it is well suited for estimating inter-cellular interference in a mixed macro-micro environment. However for better in-cell microcellular coverage with BS antennas below rooftop heights, the model has been extended to consider lateral or side diffraction around buildings as well as second order building scatter. In addition, the previous model only considered prediction areas up to 10km by 10km. The use of a novel variable terrain resolution technique has produced a significant speed-up in the model execution time for large areas [3],[4]. Basically, the terrain resolution is progressively dropped in elliptical zones around the BS and MS, with increasing distance away from the BS and MS. This technique has been extended by introducing a 400m terrain resolution zone (as illustrated in figure 2), to allow terrain areas of up to 50km by 50km to be modelled.

The model predicts time and frequency dispersion (complex channel impulse response, RMS delay spread, frequency response and coherence bandwidth), spatial dispersion (AOA in elevation and azimuth at BS and MS) as well as providing coverage/interference and fading information.

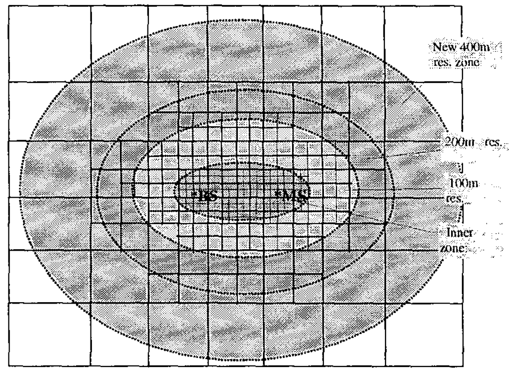

Fig. 2: Dynamic terrain resolution technique

3. Results and Validation

Figure 3 shows an example of a point-to-point prediction from the model in the prediction area in figure 1. It shows the ray paths for the dominant rays between the prediction points.

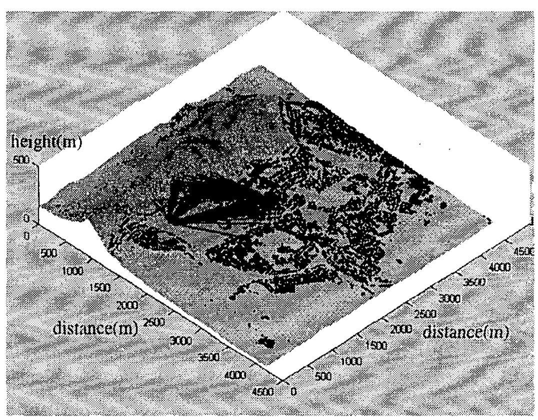

Fig. 3: Ray geometry for point-to-point prediction

This propagation model has been validated using measurement data collected in mixed urban and rural environments [3],[4]. Figures 4 and 5 show example comparisons between measurement and prediction in two very different environments, both showing very good agreements between measured and predicted signal levels (<7.5dB RMS error).

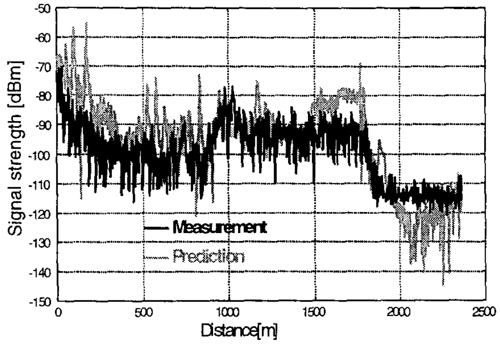

Fig. 4: Rural Validation: High Mounted BS.
Mean error: 3.5dB, Rms error: 7.5dB

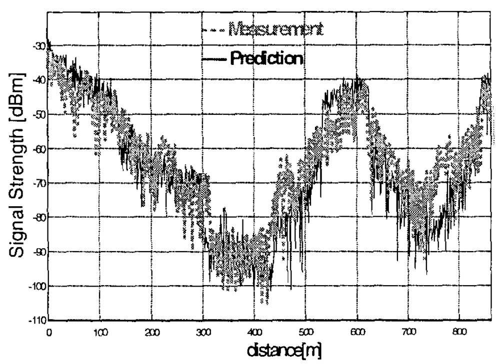

Fig. 5: Urban Validation: Low Mounted BS.
Mean error: -2.5dB, Rms error: 6.8dB

The profiles in figure 4 are for a rural area with numerous of hedges and trees, a low building density, and with a high mounted BS antenna (15m above ground) [3]. The profiles shown in figure 5 on the other hand are for an area in central Bristol with high building density, and with the BS antenna at a height of 3m above ground. Hence the two environments are representative of a typical macrocell and microcell. Clearly, the predictions show very good agreement with the measurements in both cases, illustrating that the model is equally accurate in both macrocellular and microcellular environments.

The propagation model described here is used in the PROPHECY planning tool developed at the University of Bristol. The PROPHECY tool allows the display of coverage maps as well as C/I plots, most-likely-server plots, redundancy and outage plots (for user-defined system thresholds) for multiple BS configurations, using the information obtained from the propagation model.

Figure 6 shows a coverage plot for a two BS scenario: BS2 (TX power: 30dBm) is on a hilltop (macrocell or umbrella cell) covering a large prediction area, while BS1 (TX power: 20dBm) is in a built-up area (microcell) about 2km from BS2, covering a much smaller area.

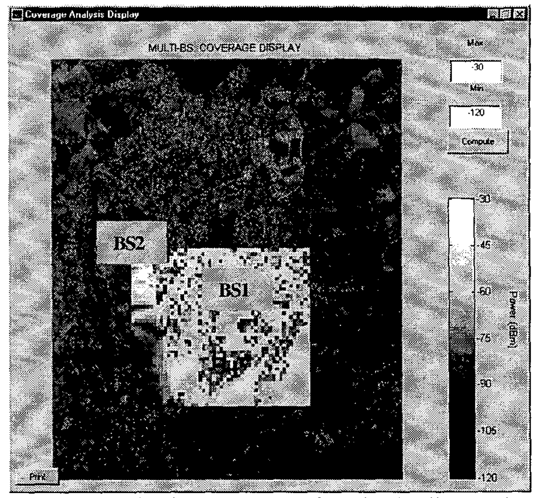

Fig. 6: Combined coverage map for mixed cell scenario

The resulting C/I plot for the microcell is given in figure 7 whilst figure 8 shows the reverse interference in the macrocell due to the presence of the microcell. The plots are superimposed on an aerial photograph of the area.

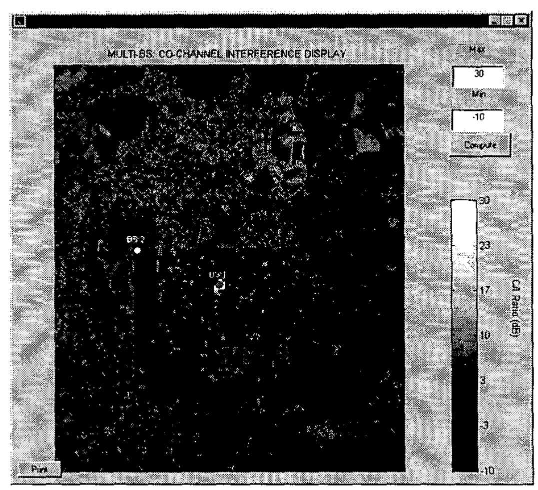

Fig. 7: C/I plot for microcell with interfering macrocell

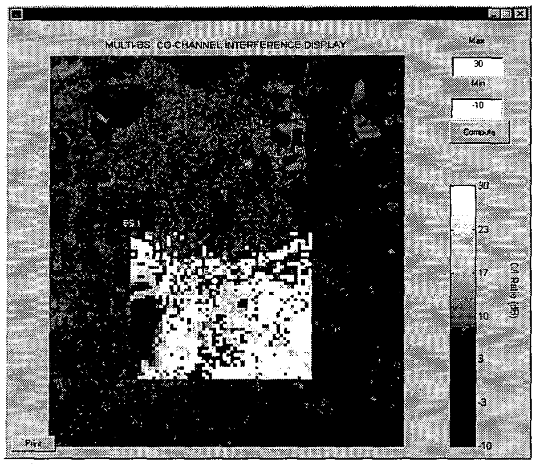

Fig. 8: C/I plot for macrocell with interfering microcell

Figure 7 shows a significant degree of interference in the microcell as a result of the hilltop BS almost 2km away. As expected, figure 8 shows a considerable level of interference in the macrocell in the region around the microcell BS. However, there is also significant interference in a small area around the left-hand edge of the macrocell. This arises as a result of the topography of the area (see figure 1) allowing almost similar levels of energy from both the microcell and macrocell BSs into this region.

A C/I plot for two interfering BSs is depicted in figure 9.

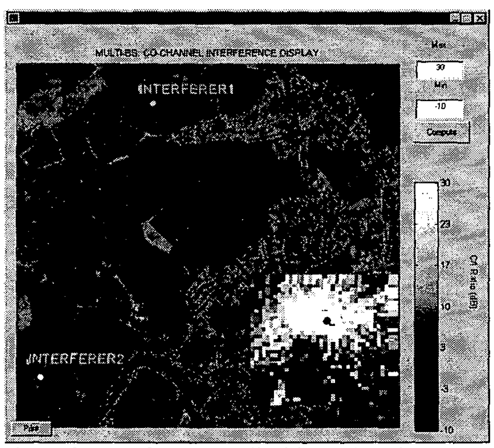

Fig. 9: C/I plot for microcell with two interfering BSs

The PROPHECY tool also allows most-likely-server (MLS) plots as well as outage and redundancy plots for multiple BS configurations. Figure 10 shows the coverage map for a three BS scenario. The coverage area for each BS shown here is rectangular in shape for simplicity and predictions are only performed inside this rectangular area for each BS. These coverage areas are user-defined and do not have to enclose the BS itself e.g. BS1 and BS3 in figure 10 are outside their prediction coverage areas.

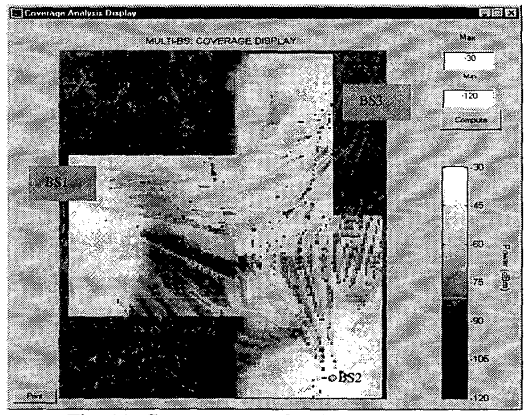

Fig. 10: Coverage map for three BS set-up.

Because the propagation model also calculates time and frequency dispersion information, the most likely server can be determined not only from the maximum received power, but also from the minimum RMS delay spread. Figure 11 shows the MLS plot determined from the maximum received power.

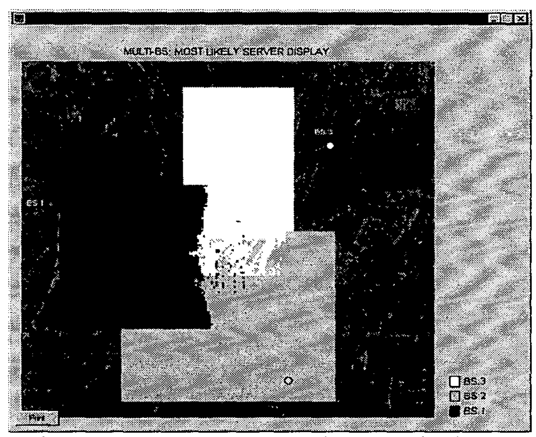

Fig. 11: MLS plot based on maximum received power

In the overlapping areas, the number of BSs meeting certain system thresholds can also be evaluated and displayed as a redundancy plot. Such a plot is shown in figure 12 together with the (user-defined) system thresholds of C/I, maximum normalised RMS delay spread, system power and minimum K factor. Any subset of these parameters can be chosen for the redundancy plot. Similarly, using the system thresholds, an outage plot for the three cells can be obtained as shown in figure 13. The solid areas in figure 13 meet the defined system thresholds.

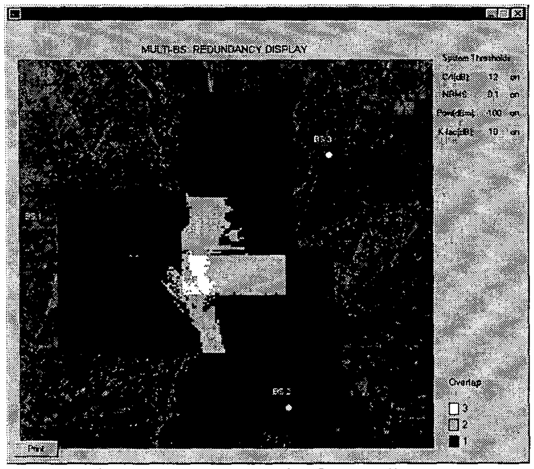

Fig.12: Redundancy plot for 3-cell setup

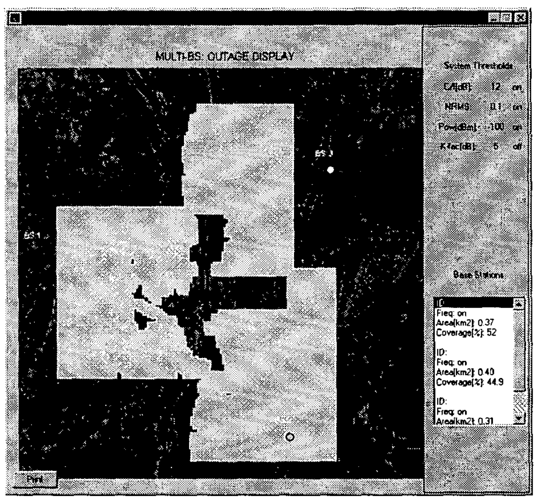

Fig. 13: Outage plot for three-cell set-up.

Again any subset of the system parameters can be used for generating the outage plot. In planning, the system thresholds can therefore either be modified until the required outage levels are met, or the heights/power levels/antennas types and/or orientation at the various BSs can be varied to give the required solution with the desired system thresholds.

4. Conclusions

With interference being the limiting effect on capacity in DS-CDMA networks and support for mixed-cell structures in UMTS, it is necessary to model propagation and hence interference between different cell types. A wideband propagation model has been presented which is optimised for propagation in mixed macrocellular and microcellular environments. By modelling large areas with irregular terrain, as well as considering individual building and foliage effects, the main propagation mechanisms in both macrocells and microcells are accurately modelled. This enables interference prediction to be made in mixed-cell networks such as UMTS. Model validation and examples of interference predictions between BSs in different cell types (macrocell and microcell) have been presented. Additional features of the PROPHECY tool, such as the ability to create most-likely-server plots, redundancy and outage plots for multiple BS configurations have also been demonstrated.

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